The next (modular) step

Mark Butts, Alex Cooperman, and Yogesh Meher, CB&I, assess mid scale modular LNG tank technology as a tool for reducing costs and scheduling.

Efficient and cost-effective construction of LNG storage tanks is vital for the global energy landscape. The growing demand for natural gas, coupled with the need for energy security, makes optimising LNG storage a priority. Streamlining the construction process of LNG tanks can lead to faster project completion, reduced costs, and increased LNG availability, ultimately benefitting both producers and consumers. Remote locations present significant challenges for on-site construction due to limited accessibility, lack of infrastructure, difficulties with transportation of materials and personnel, potential environmental constraints, and increased logistical complexities, often leading to higher costs and potential safety concerns. Construction in harsh climates can be unpredictable and costly. Additionally, high labour cost areas pose a significant challenge to the economics of a project. All these issues and concerns can be mitigated by applying modular tank technology.

As CB&I continues to innovate LNG tank designs and product delivery models to help reduce risks, improve construction schedules, and optimise overall project economics, the company has developed a comprehensive mid scale modular tank design and execution plan.

Although this article focuses on the application of modular tank technology to LNG storage, this technology and delivery model can be applied to any refrigerated product that is typically stored in double-walled tanks. Many countries are implementing stricter regulations for LNG storage, making full containment tanks a more attractive option for compliance. Full containment tanks provide enhanced safety, as the secondary liquid container is designed to both contain cryogenic product liquid and provide controlled product vapour release in case of excessive boiling. Steel full containment tanks are allowed by current LNG industry regulations (NFPA 59A-2023) and have both the primary and the secondary liquid container constructed from cryogenic grade steel. Full containment tanks are superior from a siting and real estate utilisation perspectives compared to single or double containment tank systems.

Double wall steel full containment modular LNG tanks made at the fabrication facility include the following components:

- Elevated foundation base slab with pedestals.
- Primary and secondary liquid containers with cryogenic grade steel shell and bottom (normally 9%Ni material).
- Non-brittle bottom insulation.
- Suspended deck with insulation.
- Resilient blanket wall insulation.
- All internal components including pump wells.
- Tank umbrella roof.
- All top side components, including pump platform with all piping and valving.
- Tank access system including stairways and ladders.
- Electrical, instrumentation, and fire protection systems.

Since ground and marine transportation expose the transported module to both dynamic and vibration loads, brittle materials and those sensitive to vibration should not be included. For example, cellular glass and perlite concrete should not be used for bottom insulation due to their brittleness. Additionally, perlite insulation, which is sensitive to excessive vibration, should also be excluded from the transported module.

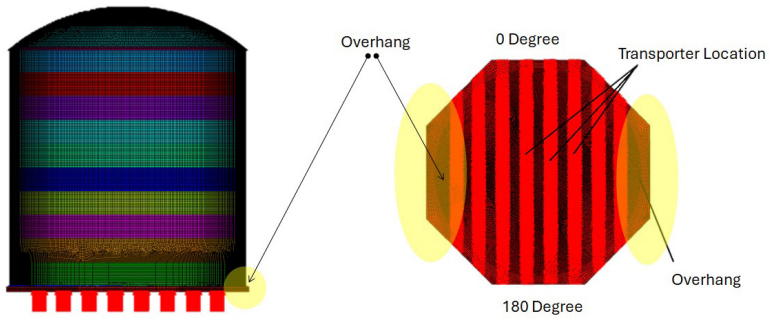

Figure 1. Module transportation on a road narrower than the tank footprint.

Once the modular tank is delivered to its destination, the remaining work at the site is minimal and should be limited to activities, such as:

- Installation of insulation components sensitive to dynamic loads and vibrations that occur during shipping, such as loose-fill perlite.
- Tank hydrotest is a mandatory field operation, as the main purpose of the hydrotest is to verify performance of the foundation and reliability of the underlying soil.
- Tank final commissioning and connection to the facility piping and electrical power systems.

The design of the modular tank and traditional field erected tank are similar. However, appropriate changes are to be made to the design, materials, and details to facilitate transportation of the modular tank to its destination.

Transportation of modular tank

Transportation of a modular tank typically includes both ground and marine components. Ground transportation of the complete module may be performed using several self-propelled modular transporters (SPMTs). Special vessels with adjustable deck elevation are normally required for module loading and marine transportation.

A comprehensive transportation study is essential for modular tank execution, encompassing both ground and marine transportation components. This study is crucial, as transportation restrictions typically determine the size and configuration of the modular unit.

To fit within the transportation restrictions from either ground or marine transportation or both, modular tanks have a higher aspect ratio when compared to conventional field-erected tanks of similar capacity. This higher aspect ratio makes modular tanks more sensitive to seismic overturning. However, because an elevated foundation with pedestals is necessary for transportation of a modular tank, seismic isolation is a natural solution in cases of high seismicity where isolators can be easily installed beneath the pedestals.

Ground transportation challenges

Loads from ground transportation may impose dimensional restrictions on either the diameter or height of the module. The restrictions on the tank diameter are dictated by width of the transportation route, including roads, bridges, and railway crossings, as well as by obstructions on the sides of the road such as power lines, ditches, and walls. The module height may be restricted by overhead power lines, height of overpasses, or other restrictions applied by local regulations. The tank footprint should allow for a sufficient number of SPMTs to be placed under the base slab to lift and move the module.

Selecting the optimal SPMT arrangement is a significant consideration for ground transportation of the modular tank. Enough SPMTs must be placed underneath the slab to lift and move the module, particularly when the road width is much narrower than the tank footprint. Additionally, in cases of narrow roads, parts of the base slab and the steel tank that overhang the

transporters may remain unsupported, potentially leading to overloading during transportation.

To illustrate this challenge, Figure 1 shows the base slab of a 41 m diameter modular tank transported on a 32 m wide road. The stresses in the base slab are shown on Figure 2. The base slab and the tank structure above are deformed, as the overhanging portions of the unit have no support. To avoid failures of the outside SPMTs, the centre SPMTs apply more pressure to the underside of the base slab to pick up more load and relieve the load from the outside SPMTs. This results in further deformation of the base slab, causing tensile stresses in the base slab to significantly exceed its concrete tensile strength. Furthermore, excessive downward deformation at overhanging portions may cause distortion and buckling of the steel tank superstructure.

Roads narrower than the tank footprint may present a significant transportation challenge. CB&I addressed this issue by developing a proprietary (patent pending) method of transporting the modular tank under pressurised conditions, generating internal pressure in the tank module using dry air. Shell uplift due to internal pressure relieves loads on the overhanging portion. At the same time, pressure adds more load to the inside SPMTs and allows distribution of the module weight more evenly among all transporters. The base slab deformations, loads on transporters, and stresses in the base slab are all within the acceptable limits, as shown in Figure 3. Also, the steel tank superstructure is not distorted or buckled.

It should be noted that while there are no physical limits on the modular tank size, both ground transportation restrictions and marine vessel availability make tank capacities up to 60 000 m^3 with diameters smaller than 45 – 50 m the most viable configurations for modular execution.

Larger modules will require extra wide roads for ground transportation, large marine loading/unloading facilities, and extra wide deck vessels, which, while they exist, are of very limited availability and higher freight costs. On the other hand, a significant number of vessels are available with a deck width up to 50 m and sufficient length to transport up to three tank modules. Transportation of multiple tank units on a single vessel minimises the number of sea voyages and reduces overall transportation cost.

Marine transportation

A marine transportation study should select the most optimal shipping route considering the time of the year, weather patterns, shelter ports, etc. The study should determine maximum horizontal, vertical, and angular accelerations

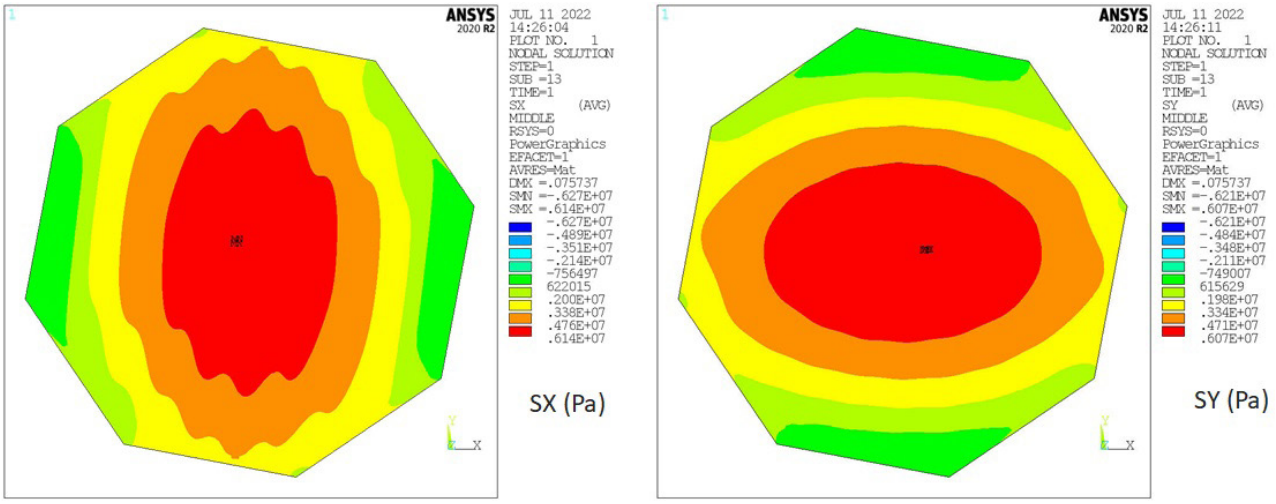

Figure 2. Stresses in the base slab for narrow road transportation (Pa).

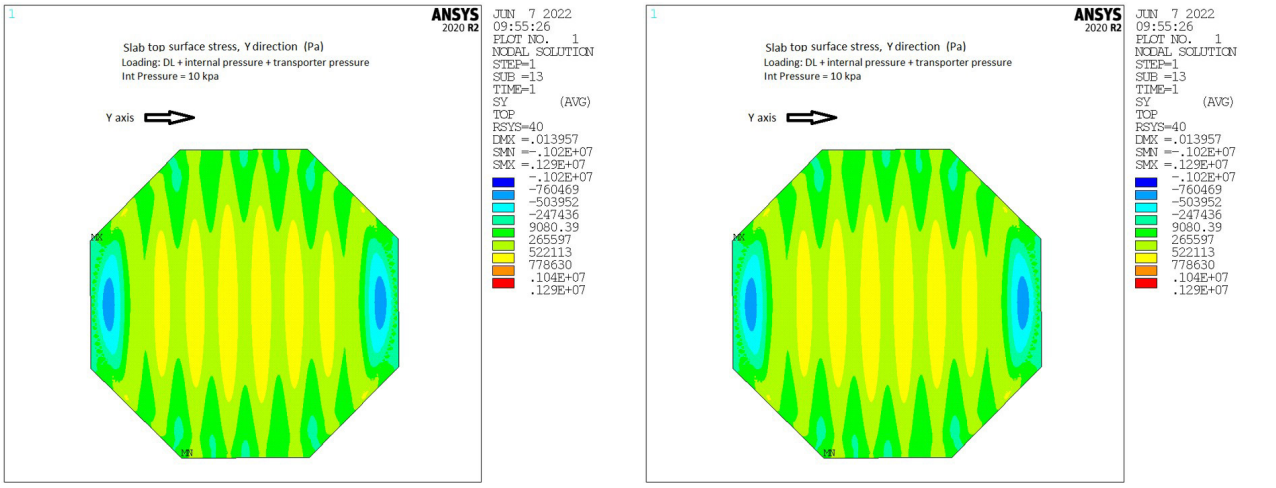

Figure 3. Base slab stresses for pressurised module transported on narrow road (Pa).

that can be applied to the shipped module during its sea voyage. The modular unit, along with its restraints on the ship deck, should be designed to accommodate the expected loads. Similar to ground transportation, marine transportation may have an impact on the size and geometry of the tank module. The factors affecting configuration of the module are the shipping loads and availability and freight cost of the appropriate size vessel.

The tank module should be designed for accelerations applied during maritime transportation. As the vessel has all six degrees of freedom, all credible load combinations due to ship motions should be considered. Also, the location of the module on the ship deck in relation to the ship's centre of gravity and rotation datum needs to be accounted for in the design of both the module and the module-to-deck restraints, since additional eccentricity loads are to be applied to the modules located closer to the bow or the aft of the vessel. Figure 4 shows an example of marine transportation of multiple modules.

Also, it is beneficial to keep the modules under low pressurisation with dry air to minimise the possibility of moisture ingress during the sea voyage. Appropriate pressure controls and pressure/vacuum-relieving devices should be included.

Cost and schedule

Cost reduction due to the use of mid scale modular tanks can be realised based on the following factors:

- Construction in a controlled environment in low-labour cost locations.
- Year-round construction with mitigated weather-related interruptions.
- Repetitive processes for multiple tanks utilising benefits of the established facility.

Overall project schedule reduction can be achieved based on the following:

- Site preparation and foundation construction are no longer on the critical path – tank construction can start in the fabrication facility even before the site earth work has begun.
- Reduction in dependency on weather-related interruptions and site conditions.
- Repetitive nature of work in the off-site fabrication facility.
- Minimising the amount of field work.

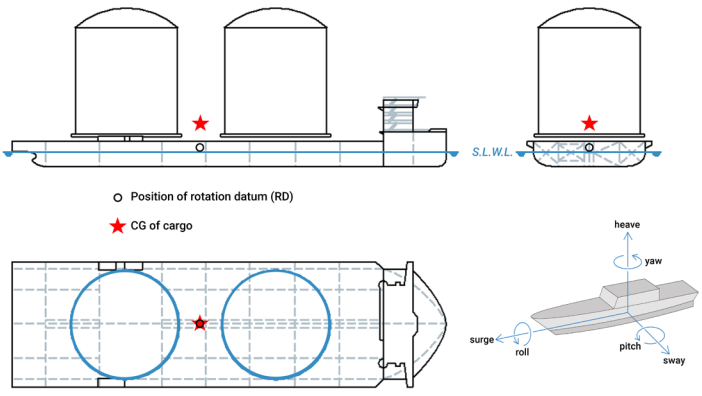

Figure 4. Marine transportation.

Case study

In order to evaluate the benefits of mid scale modular tanks when compared to traditional field-erected execution in challenging areas, a cost and schedule evaluation was performed on six modular full containment LNG tanks of 37 500 m^3 fabricated in southeast Asia and delivered to a site located on the west coast of North America. This was then compared against a single field-erected 225 000 m^3 full containment LNG tank, having a concrete secondary container constructed at the same site. The comparison showed more than 30% reduction in cost and approximately one year reduction in schedule.

The comparison of four 32 500 m^3 modular tanks fabricated in southeast Asia and shipped to a site in Australia against two 65 000 m^3 full containment field-erected tanks at the same site, having both primary and secondary liquid containers made from steel, showed approximately 10% reduction in cost and two months reduction in schedule.

Conclusions

The company's project delivery model ensures high-quality and cost-effective solutions for projects. Many customers draw on the company's deep knowledge and extensive LNG experience early in a project's development, allowing CB&I to provide input, recommendations, and project-specific solutions that enhance the long-term value of the facility. The company's integrated EPC resources enable CB&I to self-perform all aspects of the project, from conceptual design to tank commissioning.

Modular tanks are most beneficial for projects in remote locations or harsh climate areas or in regions with high labour costs, especially when multiple identical tanks are required.

In making the decision on the use of modular tank technology, both ground and marine transportation studies are very important to ensure that the modules can be safely and economically delivered to their destination.

For marine transport, the availability of suitable vessels that can accommodate the size, weight, and quantity of modular tanks is crucial. Freight costs, which can fluctuate significantly, also need careful evaluation. Ground transportation requires meticulous route planning to comply with road restrictions, including height and width. Both ports and inland transportation networks need to have the capacity to handle the movement of these modular tanks.

The use of brittle materials should be avoided. Vibration sensitive material should not be included in the transported tank modules.

Finally, field activities should be limited to vibration-sensitive tasks, such as installing tank perlite insulation material, conducting the tank hydrotest to verify the adequacy of the foundation and soil, and performing commissioning activities, including tank purge and cooldown. LNG